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1

**BROADBAND ANTENNAS**

2                   **DOCUMENTS INCORPORATED BY REFERENCE**

- 3     [0001]       The following documents are hereby incorporated by  
4       reference into this specification: Rogers, Dennis L.,  
5       "Monolithic Integration of a 3-GHz Detector/Preamplifier Using a  
6       Refractory-Gate, Ion-Implanted MESFET Process", IEEE Electron  
7       Device Letters, 1996, EDL-7, pp. 600-602; Albares, D. J.,  
8       Garcia, G. A., Chang, C. T., and Reedy, R. E., "Optoelectronic  
9       Time Division Multiplexing", Electronic Letters, 1987, 23, pp.  
10      327-328; and Mendel'son, V. L., Kozlov, A. I., and  
11      Finkel'shteyn, M. I., "Some Electrodynanic Models of Ice Sheets,  
12      Useful in Radar-Sounding Problems", Izvestiya Akademii Nauk SSR,  
13      Fizika Atmosfery I Okanea, 1972, 8, pp. 396-402 [translated in  
14      Izvestiya Academy of Sciences USSR, Atmospheric and Oceanic  
15      Physics, 1972, pp 225-229].

16

**BACKGROUND OF THE INVENTION**

17 [0002] Numerous scientific, civilian, and military  
18 applications require both narrowband and broadband  
19 communications. In typical applications, space and/or weight  
20 are at a premium and multiple frequency operation is necessary.  
21 Under these circumstances, using multiple antennas or larger  
22 broadband antennas is not practical. The use of a single  
23 antenna would eliminate cross-talk problems typically affecting  
24 multi-antenna systems, especially critical in shipboard and  
25 aircraft systems.

26 [0003] When limited space is a factor and multiple frequency  
27 operation is necessary, reconfigurable antennas provide  
28 flexibility in operating frequency, bandwidth, and radiation  
29 pattern performance. To be reconfigurable, prior designs have  
30 implemented optoelectronic or microelectromechanical systems  
31 (MEMS) switches placed along the antenna for control and  
32 sampling of electrical signals. These devices are ideal for  
33 reconfiguring antennas to different lengths, allowing for  
34 multifunctioning of the antennas. In particular, there is a  
35 need to have broadband antennas that can be reconfigured into  
36 narrowband antennas with high gain or high directionality and  
37 back to broadband for some applications.

38 [0004] A prior art concept is depicted schematically in

39 FIG. 1, where optoelectronic switches 12a, 12b, 14a, and 14b  
40 interconnect dipole antenna 20 with antenna segments 22a, 22b,  
41 24a, and 24b. The activating light is provided via optical  
42 fibers 30, resulting in complete isolation of the optoelectronic  
43 switches 12a, 12b, 14a, and 14b. When the light sources 40 and  
44 42 are in a non-emissive state, antenna segments 22a, 22b, 24a,  
45 and 24b are inactive and dipole antenna 20 has a length L with  
46 output frequency F1 at time t1. When light source 40 is placed  
47 in an emissive state, optoelectronic switches 12a and 12b are  
48 actuated, thereby activating antenna segments 22a and 22b to  
49 form a dipole antenna with length 2L and output frequency F2 at  
50 time t2. When light source 42 is placed in an emissive state,  
51 while light source 40 is also in an emissive state,  
52 optoelectronic switches 14a and 14b are actuated, thereby  
53 activating antenna segments 24a and 24b to form a dipole antenna  
54 with length 3L and output frequency F3 at time t3. The  
55 disadvantage of this system, however, is that the antenna  
56 effectively samples only one frequency at a time. During the  
57 time that this one frequency is being observed, all of the  
58 information transmitted or received at other frequencies is  
59 lost. Thus, there is a need for a variable length antenna that  
60 may be switched to allow fast sampling over an entire frequency  
61 range, providing the equivalent frequency coverage of a

62 broadband antenna while maintaining the high efficiency of a  
63 narrowband antenna.

## **SUMMARY OF THE INVENTION**

2 [0005] The present invention is a variable length antenna  
3 that may be switched to provide the equivalent function of a  
4 broadband antenna. It is an apparatus and method for quasi-  
5 continuously transmitting or receiving signals at a plurality of  
6 frequencies by changing the effective length of the antenna  
7 using a variety of switching mechanisms. The antenna of the  
8 present invention may comprise a plurality of antenna segments,  
9 a plurality of selectively actuatable switches for interconnecting  
10 the antenna segments, and a switching mechanism operably coupled  
11 to the plurality of selectively actuatable switches for switching  
12 them at a switching rate that is greater than twice the highest  
13 frequency to be transmitted or received. This rate will be fast  
14 enough to allow the antenna to sample the highest frequency and  
15 all of the required lower frequencies within the desired  
16 frequency range without the loss of information at any  
17 frequency. The switching rate is slow enough, however, to allow  
18 sampling of the frequency at each antenna length before the next  
19 antenna length is activated.

20 [0006] An example of a variable length antenna in accordance  
21 with the present invention comprises a plurality of antenna

22 segments, a plurality of selectively actuatable switches for  
23 interconnecting the antenna segments, a switch controller, and  
24 at least one light source. The light source(s), such as lasers,  
25 pulsed lasers, light-emitting diodes (LEDs) and diode lasers,  
26 may be operably coupled to the actuatable switches by a variety of  
27 means, including optical fibers, optical waveguides, optical  
28 switches, light valves, or optical MEMS devices. The switch  
29 controller selects and switches the light source(s) from a non-  
30 emissive state to an emissive state or from an emissive to a  
31 non-emissive state. As the switch controller places each light  
32 source in an emissive state, the actuatable switches are  
33 selectively actuated, thereby activating selected antenna  
34 segments and changing the length and effective frequency of the  
35 antenna. When the variable length antenna has cycled through  
36 the desired transmit or receive frequency range, the light  
37 source(s) is/are returned to a non-emissive state and the  
38 sampling process repeats.

39 [0007] Another example of a variable length antenna in  
40 accordance with the present invention comprises a plurality of  
41 antenna segments, a plurality of selectively actuatable switches  
42 for interconnecting the antenna segments, a switching device  
43 operably coupled to at least one light source for actuating the  
44 plurality of actuatable switches, and a delay mechanism operably  
45 coupled to said at least one light source for effecting delay in

46 actuating the plurality of selectively actuatable switches. The  
47 delay mechanism may comprise optical retarders operably coupled  
48 to optical fibers to change the effective lengths of the optical  
49 fibers. Alternatively, the physical lengths of optical fibers  
50 may be varied to achieve the same delay effects of optical  
51 fibers. The switching device simultaneously switches the light  
52 source(s) from a non-emissive state to an emissive state or from  
53 an emissive to a non-emissive state. When the variable length  
54 antenna is activated, the switch device simultaneously places  
~~55~~ each light source in an emissive state. The optical retarders  
~~56~~ introduce different amounts of time delay into the optical  
~~57~~ fibers, the actuatable switches are sequentially activated and  
~~58~~ thereby activating selected antenna segments and increasing the  
~~59~~ length and effective wavelength of the antenna. When the  
~~60~~ variable length antenna has cycled through the desired transmit  
~~61~~ or receive frequency range, the light sources are returned to a  
~~62~~ non-emissive state and the sampling process repeats.

63 [0008] Yet another example of a variable length antenna in  
64 accordance with the present invention comprises a plurality of  
65 antenna segments, a plurality of selectively actuatable switches  
66 for interconnecting the antenna segments, a light source  
67 operably coupled to a switching device, at least one diffraction  
68 grating operably coupled to the light source, and a delay  
69 mechanism operably coupled to said at least one diffraction

70 grating for effecting delay in actuating said plurality of  
71 selectively actuatable switches. The switching device switches  
72 the light source from a non-emissive to an emissive state or  
73 from an emissive to a non-emissive state. When the light source  
74 is placed in an emissive state, the light passes through the  
75 diffraction grating(s) to produce a plurality of new light  
76 sources after diffraction. Each new light source then  
77 selectively actuates the actuatable switches to activate  
78 corresponding antenna segments and change the effective length  
79 of the antenna.

80 [0009] In accordance with the present invention, transmitting  
81 or receiving signals at a plurality of frequencies may be  
82 accomplished by employing conductive fluid to change the  
83 effective length of the antenna. The antenna may comprise a  
84 plurality of antenna segments, each of which comprises a  
85 dielectric container for holding a conductive fluid. In this  
86 embodiment, the antenna may further comprise a reservoir  
87 connected to the antenna segments and a pressure regulator  
88 system for controlling the pressure in the antenna segments. As  
89 the pressure in the antenna segments changes, the effective  
90 length of the antenna changes. This allows the antenna to be  
91 tuned to both harmonically related and non-harmonically related  
92 frequencies.

93 [0010] In accordance with other aspects of the present  
94 invention, transmitting or receiving signals at a plurality of  
95 frequencies may be accomplished by using an electromagnetic beam  
96 to change the effective length of the antenna. The antenna may  
97 comprise a plurality of antenna segments and a source of at  
98 least one electromagnetic beam for effectively decoupling the  
99 antenna segments. Illuminating a section of the antenna segment  
100 with an electromagnetic beam decouples the segment of the  
101 antenna beyond the point of illumination from the rest of the  
102 antenna and, thus, changes the effective length of the antenna.

103 When the section is no longer illuminated with an  
104 electromagnetic beam, it recouples to the rest of the antenna.

105 [0011] An important advantage of this invention is that it  
106 provides a broadband antenna using a single variable length  
107 antenna, thus simplifying the construction of antenna arrays.  
108 This feature is important because RF communications systems may  
109 employ one antenna embodying various features of the present  
110 invention instead of multiple antennas, which would otherwise be  
111 necessary to cover the same bandwidth. This antenna is expected  
112 to find wide applications in communications applications,  
113 particularly on board ships and airplanes.

114 [0012] Moreover, the broadband sampling technique of the  
115 present invention has applications beyond conventional  
116 communications systems. For example, the multi-frequency

117 aspects of the invention will allow applications of  
118 electromagnetic sounding for surveillance and non-destructive  
119 testing. One such application in radar sounding is described in  
120 Mendel'son et al mentioned above.

121 [0013] These and other advantages of the invention will  
122 become more readily apparent upon review of the following  
123 description, taken in conjunction with the accompanying figures  
124 and claims.

1                   **BRIEF DESCRIPTION OF THE DRAWING**

2 [0014] FIG. 1 is a schematic of a prior art reconfigurable  
3 antenna.

4 [0015] FIG. 2 is a schematic drawing of the first embodiment  
5 of a variable length antenna for transmitting or receiving at a  
6 plurality of frequencies in accordance with the present  
7 invention.

8 [0016] FIG. 3 is a schematic drawing of a second embodiment  
9 of a variable length antenna for transmitting or receiving at a  
10 plurality of frequencies in accordance with the present  
11 invention.

12 [0017] FIG. 4 is a schematic drawing of a third embodiment of  
13 a variable length antenna for transmitting or receiving at a  
14 plurality of frequencies in accordance with the present  
15 invention.

16 [0018] FIG. 5 is a schematic drawing of a fourth embodiment  
17 of a variable length antenna for transmitting or receiving at a  
18 plurality of frequencies in accordance with the present  
19 invention.

20 [0019] FIG. 6 is a schematic drawing of a fifth embodiment of  
21 a variable length antenna for transmitting or receiving at a  
22 plurality of frequencies in accordance with the present  
23 invention.

#### 1 DESCRIPTION OF SOME EMBODIMENTS

2 [0020] The following description presents some embodiments  
3 currently contemplated for practicing the present invention.  
4 This description is not to be taken in a limiting sense, but is  
5 presented solely for the purpose of some embodiments of  
6 disclosing how the present invention may be made and used. The  
7 scope of the invention should be determined with reference to  
8 the claims.

9 [0021] FIG. 2 shows a first embodiment of a variable length  
10 antenna for transmitting or receiving at a plurality of  
11 frequencies in accordance with the present invention. In this  
12 embodiment, variable length antenna 100 comprises a plurality of  
13 antenna segments 110, 110a, 110b, 110c, 110d, 110e, ..., 110n, a  
14 plurality of selectively actuatable switches 120a, 120b, 120c,  
15 120d, 120e, ..., 120n, a switch controller 130, and a plurality  
16 of light sources 140a, 140b, ..., 140m. As contemplated in this

17 embodiment, light sources 140a, 140b, ..., 140m, such as lasers,  
18 pulsed lasers, light emitting diodes (LEDs), and diode lasers,  
19 are operably coupled to switches 120a, 120b, 120c, 120d, 120e,  
20 ..., 120n via optical fibers 150. However, other means, such as  
21 optical waveguides, optical switches, light valves, and optical  
22 MEMs devices, may also be used to couple light sources 140a,  
23 140b, ..., 140m to switches 120a, 120b, 120c, 120d, 120e, ...  
24 120n. Switch controller 130 selects light sources 140a, 140b,  
25 ..., 140m and switches them from a non-emissive to an emissive  
26 state or from an emissive to a non-emissive state. When light  
27 sources 140a, 140b, ..., 140m are in a non-emissive state,  
28 antenna segments 110a, 110b, 110c, 110d, 110e, ..., 110n are  
29 inactive and variable length antenna 100 has a length L with  
30 output frequency F1. Switch controller 130 sequentially selects  
31 and switches light sources 140a, 140b, ..., 140m from a non-  
32 emissive state to an emissive state. As each of the light  
33 sources 140a, 140b, ..., 140m are switched to an emissive state,  
34 switches 120a, 120b, 120c, 120d, 120e, ..., 120n are actuated to  
35 activate corresponding antenna segments 110a, 110b, 110c, 110d,  
36 110e, ..., 110n and increase the effective length of variable  
37 length antenna 100. Thus, when light source 140a is placed in  
38 an emissive state, switches 120a and 120b are actuated, thereby  
39 activating antenna segments 110a and 110b to form a dipole  
40 antenna with length 2L and output frequency F2. Next, switch

41 controller 130 places light source 140b in an emissive state  
42 which actuates switches 120c and 120d, thereby activating  
43 antenna segments 110c and 110d to form a dipole antenna with  
44 length 3L and output frequency F3. Finally, switch controller  
45 130 places light source 140m in an emissive state which actuates  
46 switches 120e and 120n, thereby activating antenna segments 110e  
47 and 110n to form a dipole antenna with length nL and output  
48 frequency Fm. When variable length antenna 100 has cycled  
49 through the desired frequency range, switch controller 130  
50 returns light sources 140a, 140b, ..., 140m to a non-emissive  
51 state, and the sampling process repeats. When the required  
52 switching and sampling times are met, variable length antenna  
53 100 resembles a broadband antenna, with the advantage of using a  
54 single highly efficient dipole antenna.

55 [0022] A second embodiment of a variable length antenna for  
56 transmitting or receiving at a plurality of frequencies in  
57 accordance with the present invention is shown in FIG. 3. In  
58 this embodiment, variable length antenna 200 comprises a  
59 plurality of antenna segments 210, 210a, 210b, 210c, 210d, 210e,  
60 ..., 210n, a plurality of selectively actuatable switches 220a,  
61 220b, 220c, 220d, 220e, ..., 220n, a switching device 230, and a  
62 plurality of light sources 240a, 240b, ..., 240m. Optical  
63 fibers 250 operably couple light sources 240a, 240b, ..., 240m  
64 to actuatable switches 220a, 220b, 220c, 220d, 220e, ..., 220n.

65 As with the first embodiment, other means of operably coupling  
66 light sources 240a, 240b, ..., 240m to actuatable switches 220a,  
67 220b, 220c, 220d, 220e, ..., 220n may be used, including optical  
68 waveguides, optical switches, light valves, and optical MEMS  
69 devices. In this embodiment, switching device 230  
70 simultaneously switches light sources 240a, 240b, ..., 240m from  
71 a non-emissive to an emissive state or from an emissive to a  
72 non-emissive state. In addition, this embodiment of the present  
73 invention includes the use of optical retarders 260a, 260b,  
74 260c, 260d, 260e, ..., 260n coupled to optical fibers 250 to  
75 change the effective lengths of optical fibers 250.  
76 Alternatively, the physical lengths of optical fibers 250 may be  
77 varied to introduce delay in the optical fibers 250 and achieve  
78 the same effects of using optical retarders 260a, 260b, 260c,  
79 260d, 260e, ..., 260n. When light sources 240a, 240b, ..., 240m  
80 are in a non-emissive state, antenna segments 210a, 210b, 210c,  
81 210d, 210e, ..., 210n are inactive and variable length antenna  
82 200 has a length L with output frequency F1. Switching device  
83 230 simultaneously switches light sources 240a, 240b, ..., 240m  
84 from a non-emissive state to an emissive state. Optical  
85 retarders 260a 260b, 260c, 260d, 260e, ..., 260n introduce  
86 different amounts of delay into optical fibers 250 to  
87 sequentially actuate switches 220a, 220b, 220c, 220d, 220e, ...,  
88 220n. Switches 220a, 220b, 220c, 220d, 220e, ..., 220n are

89 selectively actuated to activate corresponding antenna segments  
90 110, 110a, 110b, 110c, 110d, 110e, ..., 110n and increase the  
91 effective length of the antenna. Thus, when all light sources  
92 240a, 240b, ..., 240m are placed in an emissive state, switches  
93 220a and 220b are actuated first, thereby activating antenna  
94 segments 210a and 210b to form a dipole antenna with length 2L  
95 and output frequency F2. Next, switches 220c and 220d are  
96 actuated, thereby activating antenna segments 210c and 210d to  
97 form a dipole antenna with length 3L and output frequency F3.  
98 Finally, switches 220e and 220n are actuated, thereby activating  
99 antenna segments 210e and 210n to form a dipole antenna with  
100 length nL and output frequency Fm. When variable length antenna  
101 200 has cycled through the desired frequency range, switching  
102 device 230 returns light sources 240a, 240b, ..., 240m to a non-  
103 emissive state, and the sampling process repeats. As with the  
104 first embodiment, when the required switching and sampling times  
105 are met in this embodiment, variable length antenna 200  
106 resembles a broadband antenna, with the advantage of using a  
107 single highly efficient dipole antenna.

108 [0023] FIG. 4 shows a third embodiment of a variable length  
109 antenna for transmitting or receiving at a plurality of  
110 frequencies in accordance with the present invention. Variable  
111 length antenna 300 comprises a plurality of antenna segments  
112 310, 310a, 310b, 310c, and 310d, a plurality of selectively

113 actuable switches 320, a switching device 330 operably coupled  
114 to a single multi-wavelength light source 340, and a plurality  
115 of diffraction gratings 370. In this embodiment of the present  
116 invention, switching device 330 switches the single light source  
117 340 from a non-emissive to an emissive state or from an emissive  
118 to a non-emissive state. When light source 340 is placed in an  
119 emissive state, the light passes through diffraction gratings  
120 370 and produces a plurality of new light sources after  
121 diffraction. As with the second embodiment, this embodiment  
122 employs the use of optical retarders 360 to introduce delay and  
123 change the effective lengths of optical fibers 350. The  
124 physical lengths of optical fibers 350 may also be varied to  
125 achieve the same delay effects of optical retarders 360. Thus,  
126 switches 320 are sequentially actuated to activate corresponding  
127 antenna segments 310a, 310b, 310c, and 310d and increase the  
128 effective length of variable length antenna 300.

129 [0024] FIG. 5 shows another embodiment of a variable length  
130 antenna for transmitting or receiving at a plurality of  
131 frequencies in accordance with the present invention. Variable  
132 length antenna 400 is a pressure-driven liquid antenna  
133 comprising two separate liquid metal columns 410, each held in  
134 its own dielectric tube 412. The pressure in the dielectric  
135 tubes 412 is controlled by a pressure regulator system  
136 comprising of pumps 420 operably coupled to one end of the

137 dielectric tubes 412 via hoses 422 and reservoirs 424 for  
138 holding excess conductive fluid 410. Additional pumps 426 may  
139 operably couple the reservoirs 424 to the dielectric tubes 412. .  
140 Increasing the pressure in the dielectric tubes 412 in  
141 conjunction with pumping conductive fluid 410 into the  
142 reservoirs 424 shortens the length of the antenna 400. Reducing  
143 the pressure in the dielectric tubes 412 in conjunction with  
144 pumping conductive fluid 410 from the reservoir 424 lengthens  
145 the antenna. This embodiment of the present invention may be  
146 readily formed using microfabrication techniques such as those  
147 used in microfluidic and MEMS processing. In such cases,  
148 channels may be formed in dielectric material that can provide  
149 the form or structure for the antenna.

150 [0025] Another embodiment of a variable length antenna for  
151 transmitting or receiving at a plurality of frequencies in  
152 accordance with the present invention is shown in FIG. 6. In  
153 this embodiment, variable length antenna 500 comprises a  
154 plurality of antenna segments 510, 510a, 510b, 510c, . . . , 510n,  
155 and a source of at least one electromagnetic beam 520 for  
156 decoupling antenna segments 510, 510a, 510b, 510c, . . . , 510n.  
157 Illuminating a section of the variable length antenna 500 with  
158 an electromagnetic beam decouples the segment of the antenna  
159 beyond the point of illumination from the rest of the antenna  
160 and, thus, varies the effective length of the antenna. To

161 decouple an antenna segment, the intensity of the  
162 electromagnetic beam 520 must be sufficient to overwhelm any rf  
163 signal on the antenna at the point of beam illumination. Two  
164 possible sources for the electromagnetic beams are the hydrogen  
165 cyanide (HCN) laser, which has a frequency of 890 GHz, and the  
166 hydrogen atom maser, which has a frequency of 1.42 GHz.

167 [0026] An important aspect of the variable length antenna for  
168 transmitting or receiving at a plurality of frequencies is the  
169 flexibility in its range of frequencies. The number of actuatable  
170 switches and antenna segments may be increased or decreased  
171 depending on the desired frequency range. Moreover, the  
172 operation of the variable length antenna is not limited to  
173 sequentially transmitting or receiving frequencies within the  
174 frequency range. The present invention may be operated to  
175 transmit or receive frequencies in any desired sequence within  
176 its frequency range. Finally, this concept may be applied to  
177 other radiating apertures including, but not limited to, slots,  
178 spirals, and the like.

179 [0027] Obviously, many modifications and variations of the  
180 invention are possible in light of the above teachings. It is  
181 therefore to be understood that within the scope of the appended  
182 claims the invention may be practiced otherwise than as has been  
183 specifically described.